The Elimination of Leaded Motor Gasoline:
Effect on Canadian Gasoline Engines Beyond 1990

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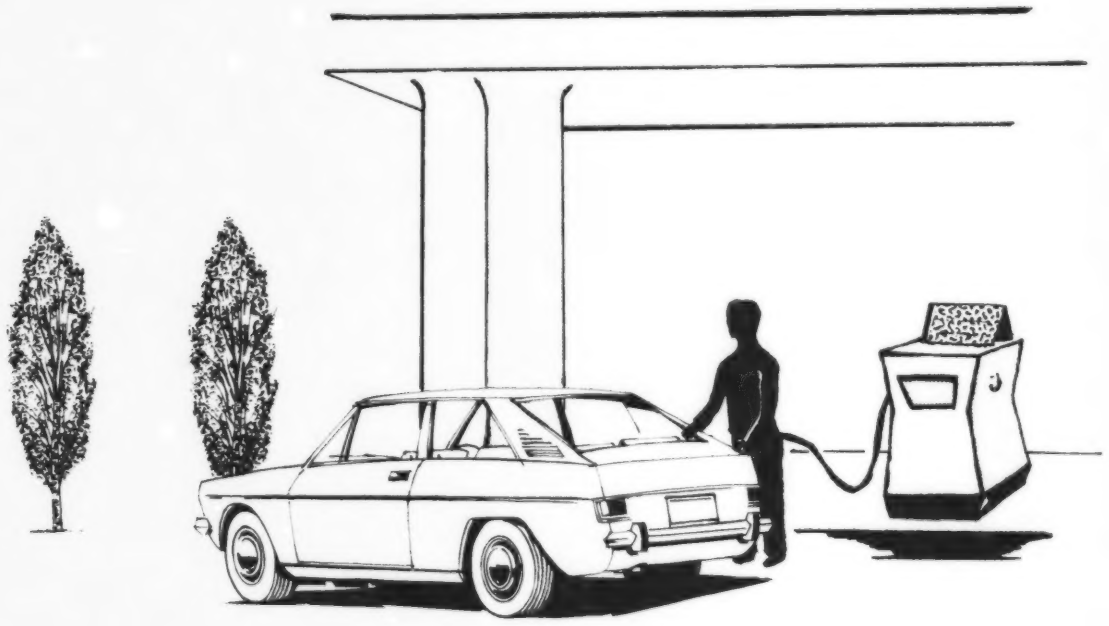

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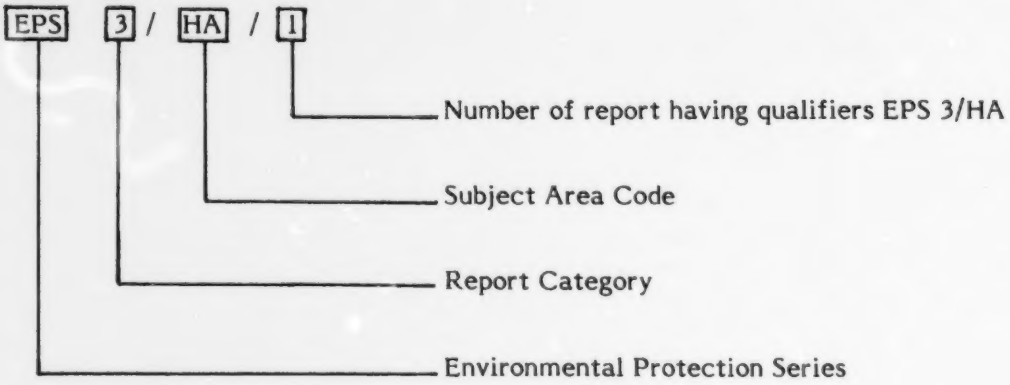
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THE ELIMINATION OF LEADED MOTOR GASOLINE:
Effect on Canadian Gasoline Engines Beyond 1990

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ABSTRACT

Increasingly in Canada, more vehicles are using unleaded gasoline as fuel. In fact, leaded gasoline will be banned in Canada, with a few exceptions, by December 1, 1990. However, there are still a number of older vehicles and motor-powered equipment in operation that were designed to use leaded gasoline. These would experience valve seat recession if unleaded gasoline is used. This report examines the problem of valve seat recession and discusses various solutions.

The properties of tetraethyl lead and its effects on engines are also discussed. Engines used in cars, trucks, farm machinery, boats, motorcycles, antique cars and boats, and lawn and garden equipment are examined for their ability to operate on unleaded gasoline and their potential for suffering valve seat recession.

Canadian vehicle populations are estimated for the equipment at risk of valve seat recession, and conclusions are reached about the magnitude of the problem and alternatives available to lessen its severity.

RÉSUMÉ

Le nombre de véhicules alimentés à l'essence sans plomb est sans cesse à la hausse au Canada. De plus, l'essence au plomb sera retirée du marché à compter du 1er décembre 1990, à quelques exceptions près.

Un certain nombre de voitures, de camions, de machines agricoles, de bateaux, de motocyclettes, de voitures et bateaux anciens, de tondeuses à gazon et autres équipements de jardinage, conçus pour fonctionner à l'essence au plomb, seront encore en service à cette date. Or, l'utilisation d'essence sans plomb dans ces cas risque d'accélérer l'usure des sièges de soupape (communément appelée affaissement de soupape).

Il est question dans ce rapport des propriétés du plomb tétraéthyle et de ses effets sur les moteurs. Le nombre de véhicules, de machines et d'équipements divers qui seront exposés à l'affaissement de soupape a été estimé afin d'examiner l'étendue du problème et les solutions possibles pour l'atténuer.

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SUMMARY

On June 21, 1986, the Minister of the Environment announced in the Canada Gazette, Part 1, that lead (Pb) would be eliminated from vehicle fuel effective December 31, 1992. Subsequent research has uncovered evidence that the health of children is affected at lower blood Pb levels than had hereto been the case. In response, the Ministers of the Environment and Health and Welfare announced on September 13, 1988, that the date for the elimination of Pb in gasoline would be moved up to December 1, 1990.

Due to concern about the durability of some gasoline-powered equipment still in service, a low Pb gasoline, containing 26 mgPb/L, will be available for farm equipment, commercial fishing boats and trucks over 3856 kg gross vehicle weight rating (GVWR). Vehicles and motorized equipment that take advantage of the lubricating properties of Pb in gasoline to prevent exhaust valve seat wear, also known as valve seat recession, include pre-1972 cars, pre-1974 light trucks, pre-1988 heavy duty trucks, 4-cycle marine engines, farm tractors and combines.

In this report, premature valve seat wear means that the valve seat wears out before it would have if the engine had been operated on leaded fuel. Excessive or premature valve seat wear will ultimately make the engine inoperable. The engine will have to be scrapped, replaced or rebuilt, depending on the age and condition of the equipment it operates.

Of the 16 million Canadian road vehicles, approximately 629 000 (3.7%) could be at risk of premature valve seat wear. Fleet studies conducted in the United States show that only 0.5%, or less, of vehicle engines which are at risk would experience premature valve seat wear if leaded gasoline was banned outright. Projections for 1990 indicate that only 16% of the estimated 663 000 farm tractors over 20 hp will have engines designed for leaded gasoline. Most of these will be concentrated in the 20 to 40 hp range and be 31 years old, on average. Based on use and the type of valve seat in the engine, it is estimated that only 36% of gasoline-powered tractors, or 6% of all tractors, will risk premature valve seat wear.

Approximately 49% of the estimated 109 000 combines in service in 1990 will be gasoline-powered, and have an average age of 24 years. Unless preventive measures are taken, combine engines will suffer rapid valve seat wear because of the high load and high engine speed normally associated with combine operation.

Engines threatened by valve recession when using unleaded fuel can be protected with a low-lead gasoline. A non-lead valve lubricating additive could also be added to unleaded gasoline and engines can be upgraded inexpensively if the work is done during scheduled rebuilding.

1 INTRODUCTION

On June 1, 1986, the Minister of the Environment announced in the Canada Gazette, Part 1, that the Leaded Gasoline Regulations would be amended to effectively eliminate Pb in fuels for vehicles with spark ignition engines by December 31, 1992. On September 13, 1988, the Minister announced that in response to new research on the effects of lead on the health of children the date for the elimination of Pb in gasoline will be December 1, 1990.

Low-lead gasoline will still be allowed for farm, commercial and marine engines which may need the lubricating properties of leaded gasoline to avoid severe valve seat recession. However, low-lead will not be universally available. Regulations limiting its distribution or decreased demand may cause some suppliers to stop manufacturing low-lead gasoline. User preference may shift towards unleaded gasoline as there is a logistical problem of keeping the two grades of gasoline on hand.

This report addresses the problem of valve seat recession, and discusses various solutions to deal with it. The problem can be stated as follows: "How to provide adequate protection to those engines designed to use leaded gasoline should leaded gasoline be unavailable?"

The option suited for a particular engine will depend on the availability of low-lead gasoline, the condition of the engine, the equipment it is mounted in, and the amount and severity of its use. The report will discuss these options and will provide information as to the type, size and number of engines that may be affected if operated on unleaded gasoline. Estimates of the number of such engines left in service are also provided.

Leaded gasoline is defined as gasoline to which Pb has been added to improve its octane quality. Low-lead gasoline is defined as gasoline to which up to 26 mgPb/L has been added to serve as a valve seat lubricant. Octane improvement at this Pb level is small.

No Pb is deliberately added to unleaded gasoline. Present regulations limit Pb in unleaded gasoline to 13 mg/L to prevent excessive contamination of unleaded by leaded gasoline, since both products use the same distribution system. The average Pb content of unleaded gasoline is much less than the maximum allowed.

2 TETRAETHYL LEAD

Tetraethyl lead ($Pb(C_2H_5)_4$) (TEL) was developed in the 1920's to increase gasoline's octane level. The refining process used at that time could not produce the high octane gasoline necessary for the engines being developed. When first introduced, Pb additives were sold in small jars and added by the retailer to the gas tank during refuelling. However, Pb is very poisonous and TEL is easily absorbed through the skin. Strict handling procedures were implemented by the industry when the dangers of handling TEL were recognized.

Today, Pb additives are sold only to refiners or to gasoline blenders as a pre-packaged mix containing TEL and/or tetramethyl lead with ethylene dichloride ($ClCH_2CH_2Cl$) and/or ethylene dibromide ($BrCH_2CH_2Br$) as scavengers. Scavengers prevent excessive Pb deposits in the engine.

Due to the safety concerns related to handling Pb additives, manufacturers will sell only to those trained to handle them properly. They will not sell Pb additives to anyone who intends to resell the product to consumers.

Lead is added to gasoline to increase its resistance to knock or 'ping'. In a gasoline engine combustion begins at the spark plug and spreads outward to the outer edges of the combustion chamber. As the air-fuel mixture burns, the temperature rises and it expands, compressing and heating the remaining unburned portion as the flame spreads to burn all of the mixture in the cylinder.

When part of the mixture spontaneously ignites and burns before the flame front arrives, a high pressure pulse is generated that is heard as knock, or ping. This pulse is like a hammer blow to the engine, greatly increasing mechanical stress and heat transfer to the combustion chamber walls and the piston. While light knock under low load is not serious, heavy knock at high load can lead to engine failure.

The octane number is a measure of gasoline's resistance to knock. Octane is measured by a special engine that compares the gasoline with mixtures of two pure chemicals: iso-octane ($(CH_3)_3C\text{-}CH_2\text{-}CH(CH_2)_2$) and normal-heptane ($(CH_3\ CH_2)_5\ CH_3$)) . Pure iso-octane has a rating of 100 and n-heptane a rating of 0. A rating of 90 octane means that the gasoline has the same resistance to knock as a mixture of 90% iso-octane and 10% n-heptane. The motor octane test (MON) and the research octane test (RON) are commonly used to rate automotive gasoline. The difference between the two are the operating conditions for the standard engine; gasoline reacts differently than the mixtures of iso-octane and n-heptane to these operating conditions.

The MON is usually less than the RON. The octane number posted at the gasoline pump is the anti-knock index (AKI), and is the average of the MON and the RON.

The advent of TEL allowed refiners to produce higher octane gasoline so that automobile manufacturers could increase the compression ratio of their engines, thus increasing engine power and efficiency. Today, new refining processes have been developed, and additives other than Pb are available. It is no longer necessary to add Pb to produce gasoline with the required octane.

3 DEMAND FOR LEADED GASOLINE

The demand for leaded gasoline has been decreasing since 1972 when unleaded gasoline was introduced. Recently, demand for leaded has decreased even faster (Figure 1). The gasoline grade split was approximately 56% leaded in May 1984, and fell to 31% by December 1987 (1). The decrease has been more dramatic in major cities such as Montreal and Toronto, where the grade split was 12% and 16% respectively.

On September 1, 1987, emission regulations under the Motor Vehicle Safety Act were amended so that the rules for exhaust and evaporative emissions from light-duty vehicles became more stringent. To meet the new regulations, all 1988 cars and light trucks are equipped with catalytic converters. The converters cannot tolerate Pb, making the use of unleaded fuel necessary. Some vehicles could meet old emission standards without a catalyst, and could therefore use leaded fuel. As many new engines also have

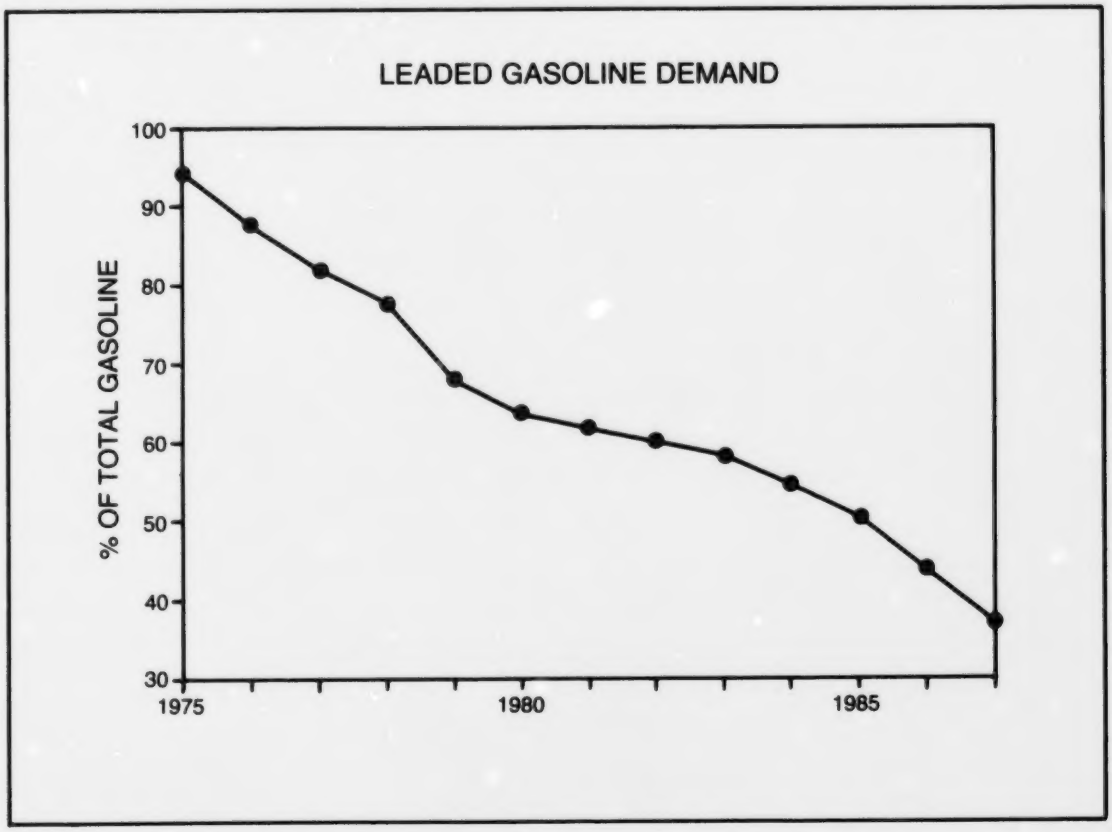

FIGURE 1 LEADED GASOLINE DEMAND

oxygen sensors, incentive to misfuel with leaded gasoline is further reduced; driveability and fuel economy suffer if the sensor is poisoned by Pb.

Similar regulations for heavy-duty trucks came into effect on December 1, 1988. Trucks up to 6363 kg (14 000 lbs.) (GVWR) must have catalysts to meet the new requirements. They too will require unleaded fuel. Most heavy-duty gasoline-powered trucks are in this weight range. Overall the number of new motor vehicles that can use leaded fuel is a small fraction of the total.

In the U.S., demand for leaded gasoline has decreased faster than in Canada. The U.S. national leaded gasoline grade split is approximately 20%. In some areas, many stations do not sell leaded gasoline, but it is still readily available in farming regions.

When demand for leaded gasoline reaches 10-15%, refiners will probably be reluctant to produce it. Even now, some U.S. refiners have abandoned production. It is estimated that Canadian demand for leaded gasoline will reach the 10-15% range before 1992-1993. It is expected that leaded gasoline will become a specialty product, made only by a few producers.

4 REGULATED LIMITS ON PB IN GASOLINE

The dangers of handling and using TEL became apparent in the 1920's after a number of workers in the lead additive manufacturing industry were poisoned. Manufacturers and users of the product responded by improving handling procedures.

Further investigation into the effects of Pb on humans prompted the United States' Surgeon General to set voluntary standards limiting the Pb content of gasoline to 3 cm^3 of TEL per U.S. gallon. As this was the maximum used by refiners at the time, this presented no real restraint. In 1958, the Surgeon General raised the level to 4 cm^3 of TEL per U.S. gallon (equivalent to 4.23 g Pb / U.S. gallon or 1.12 g Pb / L). Average U.S. industry Pb levels in the 1950's and 1960's were about 0.63 g/L.

Since regulations limited the amount of Pb in leaded automotive gasoline and the introduction of cars and trucks equipped with catalytic converters, the amount of Pb in gasoline has decreased in recent years (Figure 2). In 1974, the Pb level in unleaded gasoline in Canada was limited to a maximum of 13 mg/L (2).

The Pb content in leaded gasoline was limited to 770 mg/L as of January 1, 1976 (3) and further reduced to 290 mg/L on January 1, 1987 (4). The federal government also will effectively eliminate Pb from motor gasoline by December 1, 1990, with limited distribution of a low-lead gasoline (26 mg/L).

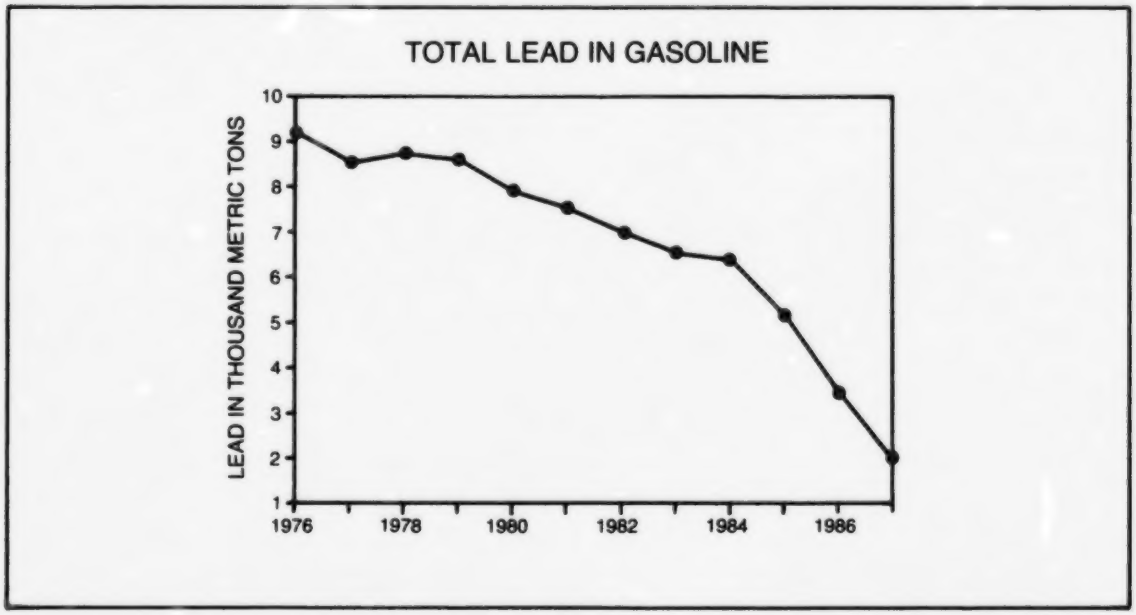

FIGURE 2 TOTAL LEAD IN GASOLINE

5 EFFECTS OF LEADED GASOLINE ON ENGINES

Besides increasing the octane rating of gasoline, TEL has a number of secondary effects on engine durability. Its only beneficial effect on an engine is the formation of lead oxide and lead sulphide (PbS) deposits on the exhaust valves and valve seats. Deposits prevent metal-to-metal contact, thus reducing wear of the valve and seat.

With the advent of catalytic converters, which require unleaded fuel, some engines had to be upgraded to compensate for the lack of lubrication. Therefore the valve seats in automotive engines with cast iron cylinder heads were usually induction hardened.

Although Pb prevents valve and seat wear, TEL can cause valve problems. Deposits can build up, then flake off, leaving an open channel for cylinder gases to wear a channel in the valve or seat face.

The scavengers used to prevent Pb deposits from accumulating in the engine can also attack the protective oxide layer on the valve face, corroding and weakening the metal. A channel can then form in the valve. Hot exhaust gas erodes the valve and it then fails.

Chlorinated scavengers in leaded fuel can combine with water in the combustion chamber to form an acid which increases internal engine corrosion and decreases the life of the exhaust system. Chlorinated scavengers are also responsible for shorter spark plug and engine oil life.

Elimination of Pb from gasoline will increase the incidence of valve seat recession in some engines. However, it will also increase spark plug and exhaust system durability and decrease engine corrosion and valve burning problems. Fleet tests and vehicle surveys with unleaded gasoline showed a small increase in valve seat recession, but overall, the number of valve problems was the same, or fewer, than in vehicles fueled with leaded gasoline (6,7,8).

5.1 Valve Seat Recession

Lack of Pb in gasoline could lead to premature exhaust valve seat wear, called valve seat recession, in some engines. Exhaust valves and seats are subjected to intense heat and high mechanical loads as the valve opens to let hot exhaust gases out of the cylinder, then closes quickly on the valve seat. Iron oxides (FeO_2, FeO_3) are found on the valve seating surface. Under high engine speed and load, small areas of the valve and the seat weld together. When the valve reopens these welded areas are subsequently

torn from the seat and raised bumps form on the valve. These high spots are pounded into the valve seat each time the valve closes, eventually causing deformation, cracking and flaking until the seat erodes (9,10). As the seat wears away, the valve will seat deeper into the head until there is no clearance in the valve mechanism. This is valve recession.

Hydraulic valve lifters can adjust for 1.8 to 3.0 mm (0.070 to 0.120 inches) of valve seat wear. Engines with mechanical lifters will have much less clearance in the valve train, and will have to be adjusted frequently. As the valve recedes into the head, the engine will begin to idle poorly and lose power due to poor flow around the recessed exhaust valve. In some instances, the recessed valve will not seal properly, and the escaping exhaust gas will burn a channel in the valve.

5.2 Valve Lubricants

Some researchers argue that the 26 mgPb/L allowed in leaded fuel in the U.S. is not enough to protect all engines from valve seat recession. However, National Institute for Petroleum Energy Research (NIPER) tests showed that this amount is enough to protect all engines tested under the duty cycles used (11).

The GM 292 engine (4.8 L) without induction hardened valve seats, did suffer valve seat recession during one test. However, this was probably due to a blown head gasket which allowed gases to flow between two cylinders. The gasket was replaced during the test, but valve recession continued. Valve recession did not occur during a repeat test with the same low-lead fuel. Tests done by others on engines with soft seats at higher speeds and loads show that 50 mgPb/L is enough to protect all engines operating under severe conditions without other additives (10, 12, 13).

Ethyl Corporation tests show that valve seat recession is reduced when methylcyclopentadienyl manganese tricarbonyl (MMT), an octane enhancer, is added to low-lead gasoline. In Canada, this compound is currently found in leaded and unleaded fuel. It is expected that MMT will also be added to low-lead gasoline. Therefore, protection from valve seat recession would be greater than found in the U.S. test programs.

Since the manufacturers will not sell TEL to the average consumer, the use of non-lead additives with unleaded gasoline as a valve and seat lubricant is a cheap and easy alternative to Pb in gasoline. The present cost of treating unleaded gasoline with non-lead additives ranges from less than $.02/L to $.12/L, depending on the additive used, quantity bought and treatment level.

Similarly, a non-lead additive is more cost-effective than rebuilding engines that are infrequently, yet intensively, used. When engines operate under extreme conditions, non-lead additives can be used to supplement low-lead gasoline.

However, although non-lead additives have proven as effective as 26 mgPb/L in eliminating valve seat recession, data as to exact quantities needed, and long-term effects are limited (11, 13).

Tests performed on non-lead additives manufactured by Lubrizol and DuPont found the DuPont product reduced the rate of valve seat recession at the concentration tested (11). However, deposits formed on the intake valves to the point where one did not close and began to burn. When tested at the manufacturer's recommended level, Lubrizol's "Powershield" reduced valve seat wear. At four times the recommended level, valve seat wear stopped. Deposits were found in the intake manifold and the combustion chamber after the Powershield tests were completed.

6 RISK AND EFFECTS OF VALVE SEAT RECESSION WHEN USING UNLEADED GASOLINE

Section 6 discusses the risk of valve seat recession when unleaded gasoline is used in various engines designed to use leaded gasoline. Low-lead gasoline will be available to many, but not all, equipment users that require leaded fuel. Some commercial operators will use unleaded gasoline because of its availability, or as a means of reducing the types of fuel that must be kept on hand.

As demand for low-lead gasoline decreases, it too, will become harder to obtain. The last part of this section examines some ways of coping with a switch to unleaded gasoline.

The most striking feature of the testing performed to date, is the difference in valve seat recession found between engines coupled to a dynamometer or run under controlled high speed tests, and those performed on vehicle fleets. Laboratory tests show a large difference between the effects of leaded and unleaded gasoline on valve seat durability, particularly in engines with soft valve seats (11,13).

However, differences did not appear in test fleets operating under typical driving conditions (6,7,8). Engines rarely operate under the severity of laboratory testing, which is specifically designed to reveal durability problems.

Valve seat recession will have a different degree of impact on different types of vehicles and equipment. The risks or impacts are discussed in the following sections.

6.1 Effect of Valve Train Design on Recession

In the late 1960's and early 1970's, automobile manufacturers and gasoline refiners realized that to meet North American pollution regulations scheduled for the mid-1970's, catalytic converters would be necessary for cars and light trucks. Lead deactivates, or "poisons", a catalyst therefore unleaded fuel must be used in all such vehicles.

At that time, the valve seats in most car and light truck engines were machined directly into the cast iron cylinder heads. Tests revealed that cast iron exhaust valve seats recessed or wore quicker when the engines used unleaded fuel. To combat this problem, automobile manufacturers induction hardened the cast iron around each valve seat to increase wear resistance.

Induction hardening is a localized heat treatment process whereby an induced electric current heats the surface of the cast iron. The red hot cast iron is then rapidly

cooled with a cooling spray. Hardening the cast iron around the seat reduced valve seat recession by 75% (10).

Valve seat inserts are used to provide a durable valve seat in new engines where the cylinder head is not hard enough. They are also used to repair worn valve seats. Engines with aluminum cylinder heads have always had intake and exhaust seat inserts regardless of fuel used. Some cast iron cylinder heads also had exhaust valve seat inserts because plain cast iron valve seats would recess, even if leaded fuel was used, if the engine was used in severe service.

Inserts are installed in a pocket or cup that is machined around each intake or exhaust port. A tight fit in the machined pocket ensures that the insert will stay in place during the large temperature changes experienced during engine operation. A good fit also ensures heat transfer from the insert to the cylinder head.

The quality of available valve seat inserts varies. The latest technology is metal powders, which are sintered or fused at high temperature, to form a seat. High temperature lubricants can also be incorporated in the insert. Metal combinations, previously impossible to fabricate, can now be sintered together.

The worst inserts for recession resistance are comparable to plain cast iron cylinder heads while the best, on the other hand, provide acceptable life under the most severe operating conditions while using unleaded fuel (14, 15).

6.2 Effect of Operating Conditions on Valve Recession

Engine speed has the largest effect on valve seat recession, while engine load has a smaller effect (16, 17). Giles and Updike reported that recession increased quickly when a 1970 model year engine was run on a dynamometer above 3000 RPM (17). This corresponds to about 113 km/h (70 miles per hour) for a car fitted with this particular engine.

Fleet tests and surveys from the early 1970's reveal that few cars develop valve seat recession when operating on unleaded fuel (6, 18). "Average" automobile operating conditions are not severe enough to cause recession in engines with soft valve seats.

6.3 Cars and Light Trucks

The most comprehensive study, comparing the effect of leaded and unleaded gasoline in pre-1970 automobiles, was conducted in the 1960's by Ethyl Corporation. The study compared 64 pairs of matched vehicles owned and driven by the Corporation's

employees (6). In each pair, one vehicle was fuelled with unleaded gasoline and the other was fuelled with leaded gasoline. The cars, using unleaded gasoline, were driven an average of 126 786 km (78 749 miles) over a 5-year period. At that time, speed limits were between 65 and 70 miles per hour on the U.S. Interstate highways.

Despite laboratory results showing that high speeds increase valve seat recession, only four of Ethyl Corporation's test vehicles using unleaded gasoline needed cylinder head replacement for that reason. In fact, one vehicle using leaded fuel required a replacement cylinder head.

Conversely, the absence of Pb reduced the number of burned and damaged valves. Six vehicles using unleaded gasoline required valve jobs, compared to 16 vehicles using leaded.

A number of subsequent field studies have compared, either directly or indirectly, the effect of unleaded fuel on engine durability (17, 18). All indicate that although engines with soft cast-iron valve seats experience slightly more valve seat recession, overall valve problems will be no higher than with leaded fuel because most privately-owned automobiles spend relatively little time at high speed. Similarly, recession should not be a problem with older cars and light trucks running on unleaded fuel provided they do not operate at high engine speed for extended periods. There will be few cars and light trucks with soft seats left in the fleet by the end of 1990 and most will not likely be used for long-distance driving.

Antique vehicles may fare better with unleaded fuel because it does not contain scavengers to accelerate engine and exhaust system corrosion. It is also unlikely that they will operate in conditions where recession poses a threat.

All cars since 1972, and light trucks since 1974, have engines with induction hardened exhaust valve seats or valve seat inserts in engines with aluminum cylinder heads. These engines were designed to run on unleaded fuel although some could use leaded because the manufacturers built certain models of their light vehicles to meet emission standards without catalysts. There are many cases where one model was sold in Canada without a catalyst while the same model sold in the U.S. with a catalyst. While the two types of engines have numerous external differences, internal construction is the same. Therefore, all cars built since 1972 and light trucks since 1974 can use unleaded fuel.

The Motor Vehicle Safety Act defines a light-duty truck as up to a maximum of 6000 lbs. (2 724 kg) gross vehicle weight rating GVWR. This is the weight of the truck and cargo for which the chassis was designed and is usually posted on the door pillar. In

1979 the definition was changed in the U.S. to include trucks of up to 8500 lbs. (3 856 kg) GVWR. This meant that all light trucks had to be designed to use unleaded fuel to accommodate a catalyst.

The Canadian GVWR for light-duty trucks was raised to 8500 lbs. (3856 kg) on September 1, 1987. Owing to different emission standards, some trucks in Canada may not have a catalyst while the equivalent U.S. model does. However, all have the same internal construction and can use unleaded gasoline.

6.4 Heavy-Duty Trucks

Trucks between 8500 and 14 000 lbs. (3856 and 6350 kg) are classed as heavy-duty, but use the same type of engines as light-duty trucks and will behave similarly when run on unleaded gasoline. However, larger trucks generally have higher axle ratios, so the engine must turn faster at a given road speed. Older trucks will start to suffer valve seat recession at lower road speeds, and will be at high risk when run at highway speeds. However, few pre-1974 trucks will be on the road by 1990. Of those that are, few will be driven for sustained periods at highway speeds. A truck which survives for 16 years is unlikely to have experienced the type of service leading to valve seat recession.

Heavy-duty trucks with induction hardened valve seats have some protection from valve seat recession when using unleaded gasoline even though they are designed to use leaded fuel. While they may suffer valve seat recession if run at high speed using unleaded fuel, many will be retired or rebuilt by 1990. U.S. emission regulations require a catalyst on most trucks up to 14 000 lbs. (6350 kg) GVWR from the 1987 model year onwards. Manufacturers have improved valves and seats so that durability is acceptable for all truck engines when using unleaded gasoline.

Under a contract funded by the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Agriculture (USDA), NIPER tested a number of engines on a dynamometer using leaded, low-lead and unleaded gasoline, plus unleaded gasoline with non-lead valve lubricating additives (11). Two engines tested, GM's 292 cubic inch (4.8 L) 6-cylinder and 454 cubic inch (7.4 L) V-8 are representative of those found in light-duty trucks and in many industrial applications.

The 4.8 L was tested on a cycle representing heavy and medium hauling at highway speeds, and also medium and low speed. The 7.4 L was tested on a cycle simulating extended time at highway speed, as would be expected from a large recreational vehicle (Appendix B).

Despite induction hardened seats, both engines suffered some valve seat recession, but were still operable at the end of the test. Valve recession appeared to have stopped. These engines, therefore, are on the borderline between recession and no recession. A small increase in operating severity would result in a rapid increase in recession while a small decrease in severity could eliminate recession entirely.

The 7.4 L was also tested with a steel valve seat insert intended for medium-duty applications. While the engine suffered valve seat recession, the inserts performed better than induction hardened seats. Recession also appeared to have stopped by the end of the test.

The 4.8 L was also tested with unhardened seats. Valve seat recession was so rapid and severe that the engine could not finish the test. This shows that under severe duty, engines with plain cast-iron seats will quickly suffer valve seat recession.

The U.S. Army also conducted tests with an engine dynamometer (14). One test engine, a Chrysler 75M 5.9 L (361 cubic inch V-8) with exhaust valve seat inserts, performed similarly to those found in civilian use. With the throttle wide open at 3200 RPM for 125 hours there was negligible valve seat recession. These tests showed that some heavy-duty engines can operate at high speed and load with unleaded fuel without suffering from exhaust valve or seat wear. The Army then tested a number of heavy-duty commercial vehicles in its fleet with unleaded fuel. The incidence of valve recession was very low and the number of valve failures was comparable to that with leaded fuel.

In 1985, 36 truck fleets were surveyed for the EPA to determine the extent of unleaded fuel use in large heavy-duty trucks designed to use only leaded (8). The overwhelming majority were using unleaded fuel exclusively. Some had converted in the 1970's, while others were more recent. One reason cited for the conversion was that some fleets also had many light-duty vehicles which used unleaded fuel. It was uneconomical to install storage tanks to hold both types of fuel. Also, as gasoline vehicles were increasingly replaced by diesels, storage tanks once used for leaded gasoline were converted to hold diesel fuel.

According to the survey report: "Most of the fleet managers reported minor tuning was necessary to maintain driving performance with unleaded, but that there were few other problems... Only seven fleet managers reported increased engine problems. These fall into two main categories-valve recession and destructive overheating. Most reported problems fall into the second category. It is probable that these overheating problems are octane related. Low octane fuels can cause significant knocking which, in

turn, can increase thermal load on an engine." (8) Larger fleets that monitored valve problems reported only 0.5% of engines in heavy-duty trucks developed valve seat recession when using unleaded fuel.

Octane related problems were caused by the lower minimum octane level of unleaded gasoline (87 AKI) compared to leaded (88 AKI). Gasolines with the same AKI will not necessarily perform the same in all vehicles (20).

Octane related problems can be prevented by making sure that timing is set to specification, that the engine is in good mechanical condition, and that the cooling system is functioning correctly. Operators can be trained to recognize knock so that it can be corrected before damage occurs. If octane problems persist, higher octane gasoline can be used.

6.5 Farm Equipment

NIPER tested four tractor engines, one combine engine and two truck engines on unleaded, leaded and low-leaded fuel for a joint EPA/USDA test program (11). The choice of engines was based on the number of each type in use rather than hours of use, or economic value. All tractor engines had either cast-iron cylinder heads without hardened valve seats or soft valve seat inserts. Under test conditions with unleaded fuel, some engines did suffer valve seat recession (Appendix B).

Two tractor engines reached rated power below 1700 RPM without suffering any abnormal valve seat wear. This indicates that the incidence of valve seat recession should be low for tractors operating at low engine speed.

Preliminary analysis of data from a 1986 U.S. survey of cylinder heads removed from farm tractors shows that approximately 30% have hard valve seat inserts. These would be invulnerable to valve seat recession when operated on unleaded fuel (19).

Many combines are powered by industrial versions of automotive engines and normally operate at high load and speed. NIPER test results show that the 292 (4.8 L) and 454 (7.4 L) GM engines show valve seat recession when operating on unleaded gasoline. This has serious implications for combines. Gasoline-powered swathers and mower conditioners often use industrial versions of automotive engines also, but since they are not loaded as highly as combines, valve seat recession should not be as severe.

The Wisconsin heavy-duty air-cooled gasoline engine is frequently found in farm and industrial equipment. The company does not expect problems with valve seat recession in their newer engines; those with model number designations ending with a "D", or with a number such as W4-70. Most of their older engines have valve seat inserts and if

they experience premature wear can be retrofitted with newer valves and inserts designed for unleaded fuel. However, this does not appear to be common even on these older engines.

In its owner's manual, Teledyne recommends removing the cylinder head and cleaning away deposits every 200 to 250 hours of operation (26). Changing valves and seats during scheduled maintenance will decrease the time and cost of modification.

6.6 Boats

Outboard motors do not have exhaust valves and most, therefore, can operate on unleaded fuel without damage. Some, made by OMC between 1970 and 1985 inclusively, may require timing changes and the installation of a modification kit. Owners should consult the dealer for more details.

With the exception of the 4-cylinder Mercruiser, inboard or stern drive engines are marine versions of automotive engines. Automotive engines have had hardened valve seats since at least 1974 and the Mercruiser 4-cylinder since 1975. It is difficult to predict how newer marine engines will last since much depends on operating conditions. Long periods at high load and high RPM, such as normal pleasure boat cruising speeds, will cause some engines with induction hardened valve seats to wear prematurely. The process will be much quicker in older engines that do not have hardened valve seats.

Since fishing boat engines also operate at high RPM and high load, valve seat recession could be a problem, even with induction hardened seats. Under these operating conditions these engines will have to be overhauled quite frequently. Premium valve seat inserts could be added during overhaul to allow the engines to operate on unleaded fuel.

Many owners of smaller fishing boats replace worn out gasoline engines with used car or light truck engines which, until recently, could operate on leaded fuel even if the original vehicle used unleaded. However, newer light-duty engines cannot use leaded fuel because their computer-controlled fuel injection systems have an oxygen sensor which requires unleaded fuel. If rebuilt, engines can be converted to unleaded fuel with the addition of premium valve seat inserts. Replacement engines will normally have acceptable durability while operating on unleaded gasoline.

6.7 Motorcycles

Environment Canada asked several associations to comment on the elimination of leaded gasoline (Appendix D). The Canadian Motorcycle Association replied:

> "Our investigation of the situation reveals that all machines manufactured from 1978 onward can accommodate unleaded gas. Therefore, we cannot see any

inconvenience to the motorcycling public which would be generated by this regulation."

All motorcycles with two-stroke engines do not have exhaust valves and will, therefore, be unaffected by a ban on leaded gasoline. Their only requirement is that fuel meet the manufacturer's octane recommendations. This also applies to other vehicles powered with two-stroke engines such as snowmobiles.

6.8 Antique Cars and Boats

It is unlikely that antique car or boat engines would be operated severely enough to cause valve seat recession. Section 6.10 describes alternatives for those few at risk.

6.9 Lawn & Garden Equipment

Members of the Canadian Outdoor Power Equipment Association commented on the phaseout of leaded gasoline. For example, Tecumseh Products Company wrote:

> "Tecumseh engines will not be adversely affected, in any way, by the use of lead-free gasoline fuels. In fact, we recommend a fresh, clean unleaded regular automotive gasoline - leaded regular grade gasoline is an acceptable substitute. This applies to two and four-stroke cycle engines, both of current and previous production."

Briggs & Stratton also reported that their engines work excellently on unleaded gasoline. Outboard Marine of Peterborough Ontario, a manufacturer of lawn mower engines, indicated that the elimination of Pb in gasoline will not effect their engines adversely.

Four U.S. Army bases converted to unleaded fuel, on a trial basis, between 1972 to 1975 (7). A wide variety of small equipment such as chain saws and lawnmowers was included. No unusual problems were reported when unleaded fuel was used.

Based on this trial and information provided by manufacturers, the elimination of leaded gasoline should not affect machinery fitted with small gasoline engines like lawn and garden equipment.

6.10 Discussion - Coping With a Ban on Leaded Gasoline

The previous sections identified which engines would be at risk of accelerated exhaust valve and seat wear if operated on unleaded gasoline. This section discusses ways of reducing the effect on engines designed to use leaded gasoline.

There are a number of things that can be done:

1) Reduce engine speed and do not operate under conditions to risk valve seat wear. This is not practical for many operators.
2) Mix valve saver additives (sold at automotive supply stores) with unleaded gasoline. Additives are now distributed in the U.S. and should be widely available in Canada by 1990.
3) Rebuild existing gasoline engines using high quality valves and valve seat inserts. The engine would be able to operate on unleaded gasoline with normal exhaust valve seat life.
4) Repower the equipment with an engine designed to meet anticipated operating conditions using unleaded gasoline. A diesel engine is another option.
5) Once the engine fails, scrap the vehicle.

Obviously, the first option is not practical for all vehicles, but many will be old and used only to supplement newer equipment. This is often the case on farms where the gasoline tractor is used only to supplement the newer diesel tractor(s) during peak periods. Similarly, older fleet equipment can be used for low-speed inner city work.

Additives are an interim step, prolonging equipment life until it is retired or converted to use unleaded gasoline or diesel fuel. Croudace and Wusz showed that non-lead additives can be as effective as 26 mgPb/L in reducing valve seat wear, however, development is still needed to determine correct treatment levels and to insure that additives will not cause long-term durability problems (13).

Rebuilding gasoline engines is normally only applicable to vehicles and equipment that will wear out one or more engines during their lifetime. The cost of installing valve seat inserts ranges from $600 to $1000. However, if done when an engine is being rebuilt, the cost of adding exhaust valve seat inserts and premium valves is only an additional $150 to $200.

The alternative to rebuilding is installing a new engine. A diesel engine is often substituted to reduce operating costs. Rebuilding a gasoline engine or repowering with a diesel are two of the best solutions for intensively used vehicles or equipment.

Some equipment at risk of valve recession is now near the end of its useful life. For some equipment operators, changing over to unleaded gasoline and running an engine until it wears out is the cheapest solution.

7 THE NUMBER OF VEHICLES AT RISK OF VALVE SEAT RECESSION IN 1990

This section quantifies each type of engine that risks valve seat recession if operated on unleaded fuel. The total Canadian vehicle population is also given.

7.1 Road Vehicles

Table 1 lists the estimated 1990 Canadian on-road vehicle population and its relative susceptibility to valve seat recession. Estimates were derived from vehicle registration data, allowing for population growth. The relative portion of vehicles in each category is based on U.S. population distributions from MOBILE 3, an emission modelling program, developed by the EPA. Canadian registration data shows that estimates for older cars and trucks are high and, therefore, overestimate the number of older vehicles at risk. As reported in sections 6.0 to 6.4, few vehicles at risk will experience rapid valve seat wear when Pb is banned from gasoline.

7.2 Farm Equipment

7.2.1 Tractors. Tractors and combines are the only types of farm equipment considered to be at risk. Table 2 shows the estimated make up of the 1990 tractor fleet. Appendix C discusses the methods used to calculate these estimates.

Most gasoline-powered tractors are in the lower horsepower category and are used infrequently and at low loads. A 1986 EPA/USDA survey of gasoline farm tractors showed that approximately 40% of all tractors were gasoline-powered (19). The average gasoline-powered tractor was 26 years old and was used an average of 250 hours per year. Approximately 42% were used exclusively for light-duty tasks and unlikely to suffer valve seat recession.

A 1986 survey of tractor cylinder heads found that 33% had hard valve seats. A number of the tractors with cast iron valve seats operate at low RPM and, therefore, have a low risk of developing valve seat recession.

While the Canadian tractor fleet should resemble its U.S. counterpart, a smaller, but similar survey was conducted in Canada to confirm the U.S. data. In 1986, Statistics Canada conducted a telephone survey of 500 New Brunswick farms. This province was chosen because the 1981 Farm Energy Use Survey showed that gasoline expenditures per machine were the highest in Canada (21).

TABLE 1 RISK OF VALVE SEAT RECESSION IN THE 1990 ON-ROAD VEHICLE POPULATION

Number of Vehicles With a Risk of Valve Recession Under Severe Conditions

Type	Low	Medium	High	Total
Cars	12 793 000 (1972=+ MY)	-	97 000 (1972 MY)	12 890 000
LDTI	1 556 000 (1974=+ MY)	-	64 800 (1974 MY)	1 621 000
LDT2	948 000 (1979=+ MY)	161 800 (1974-1978 MY)	46 200 (1974 MY)	1 156 000
HDGT	128 000 (1988=+ MY)	238 500 (1974-1987 MY)	20 500 (1974 MY)	387 000
HDDT				282 000

LDT1 - Trucks 0-6000 lbs. GVWR (2722 kg)

LDT2 - Trucks 6000+ to 8500 lbs. GVWR (2722 kg - 3856 kg)

HDGT - Trucks 8500+ lbs. GVWR (3856 kg +)

HDDT - Diesel trucks over 8500 lbs. GVWR (3856 kg)

MY - Model Year

Low Risk : Vehicles designed to use unleaded fuel.

Medium Risk: Vehicles in this category may have shorter valve seat life when driven under high speed or very high load conditions. All these vehicles have induction-hardened seats or valve seat inserts.

High Risk : Cars and light trucks in this category will suffer rapid valve seat recession when run at high speed and load. Most heavy trucks in this category have valve seat inserts which offer some protection from valve seat recession. Risk of valve seat recession is overstated.

Although the tractors were the same average age as those surveyed in the U.S., in Canada a higher proportion were used exclusively for light-duty work. Forty-eight percent were used in light operations, compared to 42% in the U.S. This is probably due to the proportionately smaller size of the Canadian gasoline-powered tractor fleet; an estimated 29% of all tractors, compared to 40% in the U.S. A large number of gasoline-powered tractors are under 20 hp (14.9 kW). Thirteen to 29% of tractors between 20 and 99 hp

TABLE 2 1990 GASOLINE AND DIESEL TRACTOR POPULATION ESTIMATES

POWER	POPULATION	% OF GASOLINE TRACTORS*		
		High	Medium	Low
20-49 hp	194 864	31	27	22
50-99 hp	276 476	17	14	0
20-99 hp	471 340	23	20	13
100+ hp	192 002	All diesel-powered		
All Tractors	682 044	18	16	7

* Percentage calculated on the basis of scenarios adopted to estimate the number of tractors that will be out of service by 1990. See Appendix C.

(14.9-73.9 kW) will use gasoline by 1990. Tractors above 99 hp generally use diesel fuel. (Appendix C - Tractor populations).

The study also showed that 40% of the fleet's total running time was spent performing medium-to-hard work. Since infrequent use and light loads prolong a tractor's life, it is assumed that 40% of all gasoline-powered tractors will be vulnerable to valve seat recession. Therefore, at the most, 10% of all tractors may experience shorter engine life if leaded fuel disappears. By the end of 1990, the average gasoline tractor will be 30 years old.

7.2.2 Combines. In fact, only diesel-powered combines have been manufactured since 1980, and few gasoline-powered combines were sold in the 1970's. Even so, the proportion of gasoline to diesel powered combines is higher than for tractors; an estimated 52% to 60% of the 1986 Canadian self-propelled combine population was gasoline-powered. Estimates for 1990 range from 37 to 53% gasoline-powered, not including pull-type combines (Table 3 and Appendix C).

Older combines are generally smaller than newer models and used for less hours per year. Gasoline combines account for a smaller proportion of total hectares harvested than their relative numbers would indicate. The EPA/USDA study reports that self-propelled gasoline combines harvested an average of 89 ha (220 acres) in 1986 (19). In Canada, each combine, including the pull type, harvested an average of 167 ha (412 acres) in the same year. This was calculated from Statistics Canada data which gives the total

TABLE 3 1990 GASOLINE AND DIESEL COMBINE POPULATION ESTIMATES

TYPE	POPULATION	% OF GASOLINE SP COMBINES*		
		High	Medium	Low
SP Combines	109 320	53	49	37
Pull Combines	44 500			

* Percentage calculated on the basis of scenarios adopted to estimate the number of combines that will be out of service by 1990.

number of acres harvested for various crops and the 1986 census which gives the total number of combines.

Gasoline-powered combines are designed to operate for 2000 to 3000 hours, which is less than tractors. They are also fitted with different engines. Many combines use industrial versions of automotive engines rather than special agricultural engines. Unlike older tractors which are often used exclusively for light duty work, combine engines always operate under high speed and load. The engine is sized to operate the combine to which it is installed.

The EPA-USDA report (19) states that the average gasoline powered combine is 19 years old. Although there is no direct data, based on the information available for tractors, Canadian gasoline combines should be the same age or older than those in the U.S.A.

7.3 Boats

7.3.1 Pleasure Boats. In 1985, there were approximately 2.3 million pleasure craft in Canada: approximately one million (45%) were powered by outboard engines, 92 000 (4%) were inboard/outboard and 20 000 (1%) were inboard (22). Because no data was available on the age distribution of pleasure boats, as a conservative estimate, it is assumed that all inboard/outboard and inboard engines are at risk.

7.3.2 Fishing Vessels. The total number of fishing vessels, including those from Newfoundland, New Brunswick, Prince Edward Island, Quebec, British Columbia and those from fresh water fisheries approaches 40 800. All large fishing vessels are diesel powered. Small fishing boats are powered by outboard engines that can use unleaded fuel. Mid-size boats use either diesels or gasoline engines. It is estimated that 6800 (17%) fishing vessels are powered by four stroke gasoline engines (27,28).

8 CONCLUSIONS

Decreasing demand for leaded fuel will eventually prompt some manufacturers to stop producing it. This has already started in the United States. As the availability of leaded fuel decreases, users of equipment at risk of valve seat recession will have to cope.

In Canada, a retail sales ban of leaded gasoline in 1990 will have little effect on the durability of gasoline engines because:

1) Only small percentage of engines in any particular type of equipment requires leaded gasoline to ensure adequate valve seat life.
2) Few engines at risk operate under conditions severe enough to cause valve seat recession.
3) Additives other than Pb are available to lubricate valve seats. Engines can be modified at a reasonable cost to run on unleaded gasoline.
4) Low-lead gasoline containing 26mgPb/L will be allowed for farm machinery, marine engines and trucks over 3856 kg (8500 lbs.) GVWR. Most engines at risk of valve seat recession are found in these categories.

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APPENDIX A*
TYPE OF VALVE SEATS USED IN HEAVY-DUTY TRUCKS

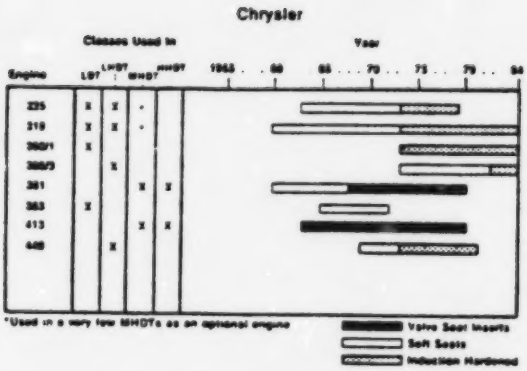


Figure 2. Use of Valve Seat Inserts and Induction Hardening in Chrysler Truck Engines.

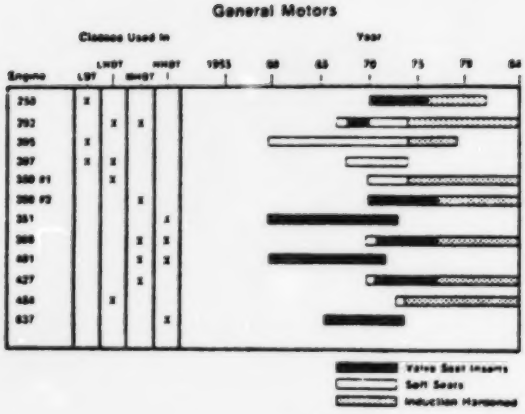


Figure 4. Use of Valve Seat Inserts and Induction Hardening in General Motors Truck Engines.

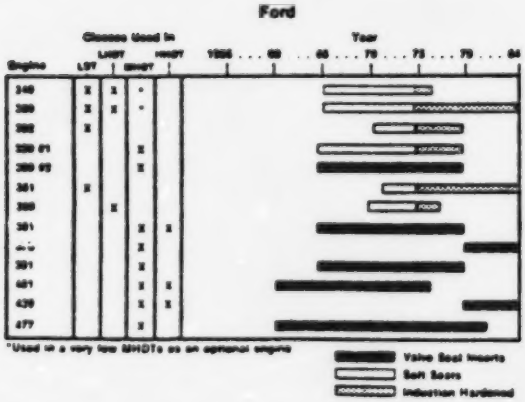


Figure 3. Use of Valve Seat Inserts and Induction Hardening in Ford Truck Engines.

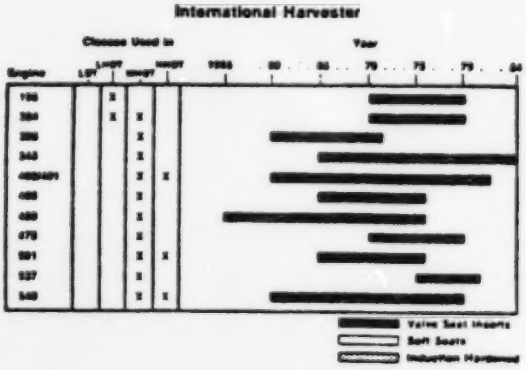


Figure 5. Use of Valve Seat Inserts and Induction Hardening in International Harvester Truck Engines.

*Reproduced from reference 24

APPENDIX B
DUTY CYCLES USED IN NIPER ENGINE TESTS AND PARTIAL RESULTS

Table 1 Characteristics of the test engines

Engine make/model	CID	# Cylinders	HP	Rated RPM	CR1/	Valve rotators
John Deere B tractor	190.4	2	24	1,250	4.7:1	No
Farmall H tractor	152	4	24	1,650	5.9:1	No
Ford 8N tractor	120	4	23	2,000	6.7:1	Yes3/
IH 240 tractor	123	4	27	2,000	6.8:1	Yes
John Deere 303 combine	303	6	80	2,500	7.6:1	Yes
GM 292 truck2/	292	6	120	4,000	8.0:1	Yes3/
GM 454 RV	454	V-8	210	4,000	9.1:1	Yes3/

1/ Compression ratio.
2/ Two GM 292 engines were tested, designated A and B
3/ Exhaust valves only

Table 2 Summary of Speed and Load Conditions for the Engine Tests

Speed and load	Mode 1	2	3	4	5	6	56-hour
John Deere "B"							
RPM	1260	1370	1300	1250	1300	1275	1275
Torque, ft/lb	86	0	43	max	21	64	76
Ford 8N							
RPM	2050	2200	2100	2000	2150	2100	2100
Torque, ft/lb	56	0	28	max	14	42	50
IH 240							
RPM	2050	2200	2100	2000	2150	2100	2100
Torque, ft/lb	73	0	37	max	18	54	64
Farmall "H"							
RPM	1700	1800	1750	1650	1750	1725	1725
Torque, ft/lb	85	0	43	max	21	64	75
John Deere 303							
RPM	2600	2750	2700	2500	2700	2650	2650
Torque, ft/lb	143	0	71	max	36	107	126
GM 292							
RPM	3000	3000	2500	2000	3600	NA	NA
Torque, ft/lb	168	89	92	53	149	NA	NA
GM 454							
RPM	3000	2000	3600	2500	3000	2500	3000
Torque, ft/lb	285	145	259	149	151	282	175

*Reproduced from reference 25

Figure 1

Exhaust Valve Seat Recession
John Deere 8, unleaded fuel, run 1
cast iron valve seats

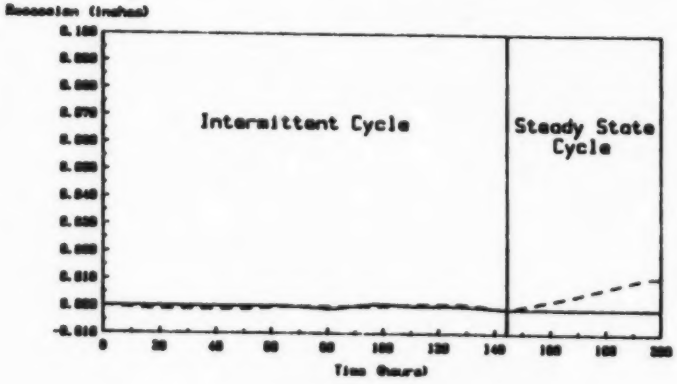


Figure 2

Exhaust Valve Seat Recession
John Deere 8, unleaded fuel, run 2
cast iron valve seats

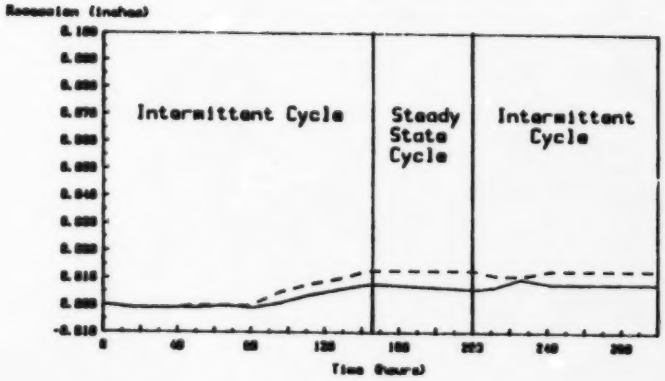


Figure 3

Exhaust Valve Seat Recession
Farmall H, unleaded fuel
cast iron valve seat inserts

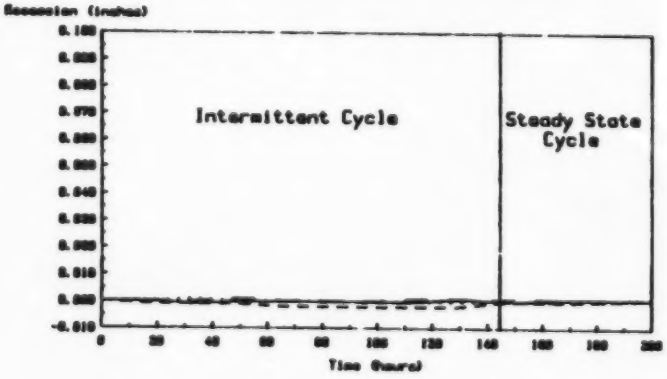


Figure 4

Exhaust Valve Seat Recession
John Deere 303 CID, unleaded fuel
cast iron valve seats

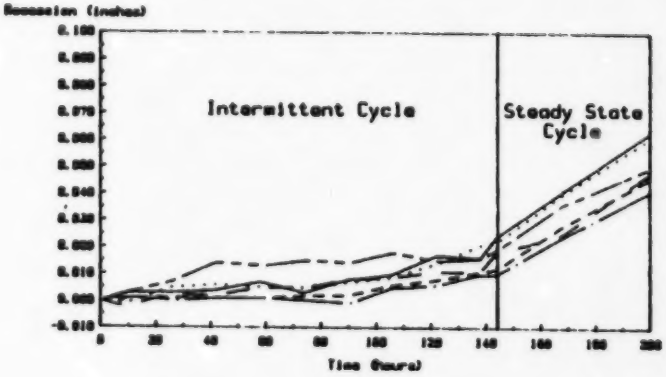


Figure 5

Exhaust Valve Seat Recession
IH 240, unleaded fuel, run 1
cast iron valve seats

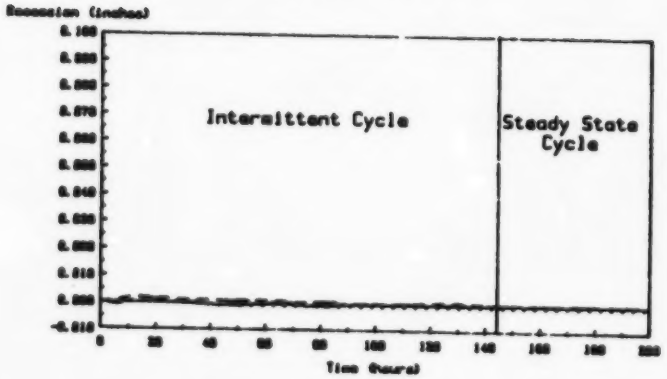


Figure 6

Exhaust Valve Seat Recession
IH 240, unleaded fuel, run 2
cast iron valve seats

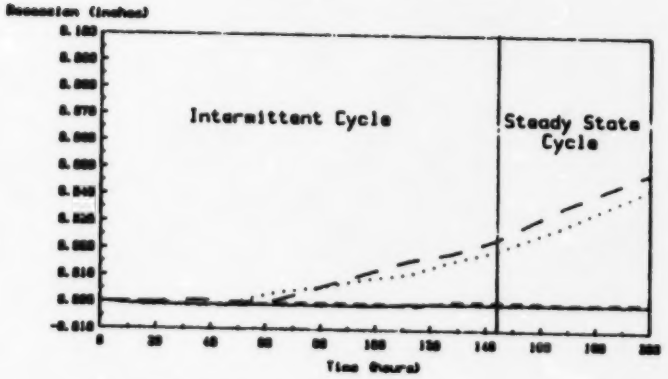


Figure 7

Exhaust Valve Seat Recession
IH 240, unleaded fuel, run 3
cast iron valve seat inserts

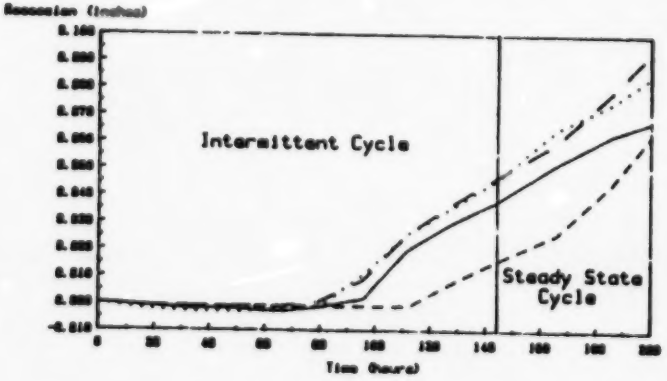


Figure 8

Exhaust Valve Seat Recession
Ford 8N, unleaded fuel
cast iron valve seat inserts

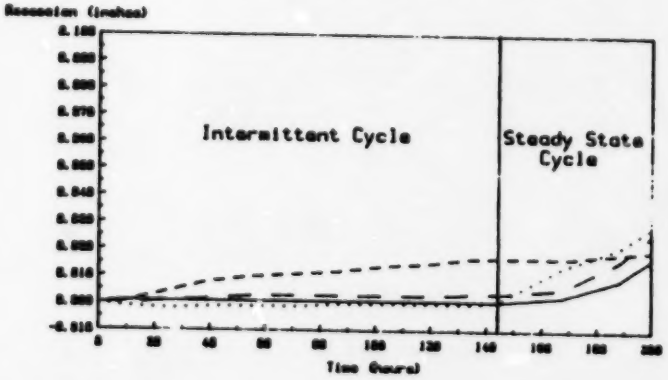


Figure 9

Exhaust Valve Seat Recession
GM 292-A, unleaded fuel
cast iron valve seats

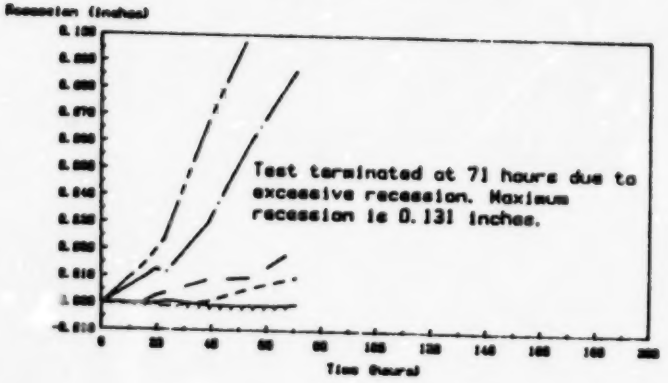


Figure 10

Exhaust Valve Seat Recession
GM 292-B, unleaded fuel
cast iron valve seats
lighter duty cycle

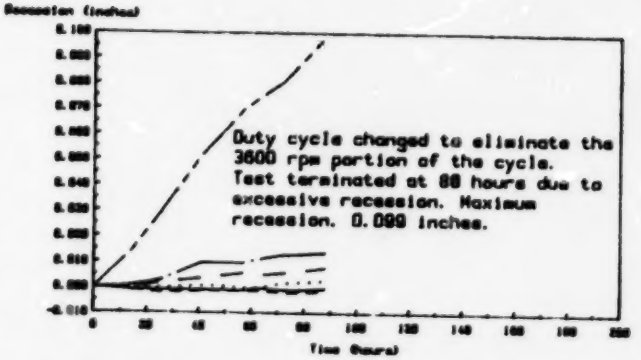

Duty cycle changed to eliminate the 3600 rpm portion of the cycle. Test terminated at 88 hours due to excessive recession. Maximum recession. 0.099 inches.

Figure 11

Exhaust Valve Seat Recession
GM 292-B, unleaded fuel
induction-hardened cast iron valve seats

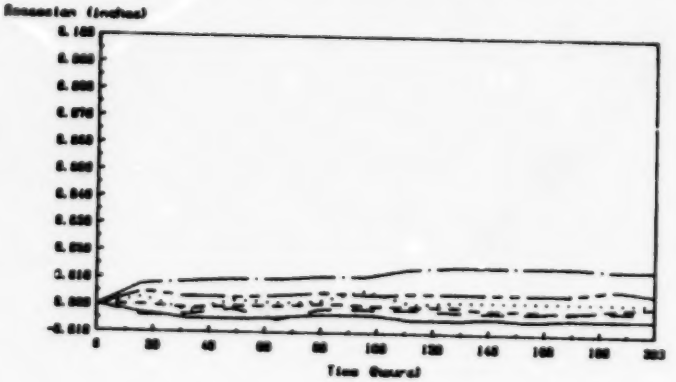


Figure 12

Exhaust Valve Seat Recession
GM 454, unleaded fuel
induction-hardened cast iron valve seats

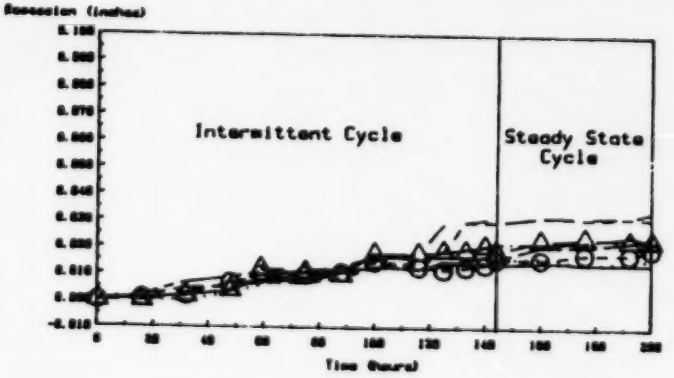


Figure 13

Exhaust Valve Seat Recession
GM 454, unleaded fuel
steel valve seat inserts

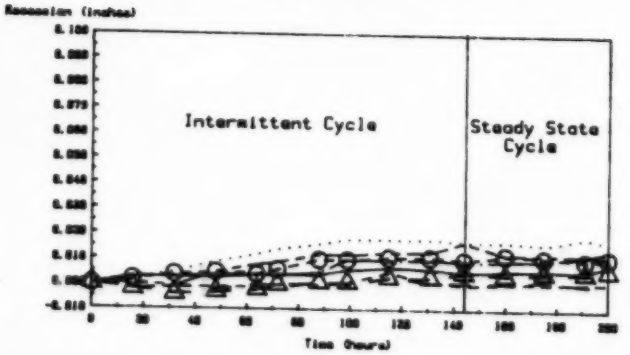


Figure 14

Exhaust Valve Seat Recession
John Deere 303 CID, 0.10 gplg
cast iron valve seats

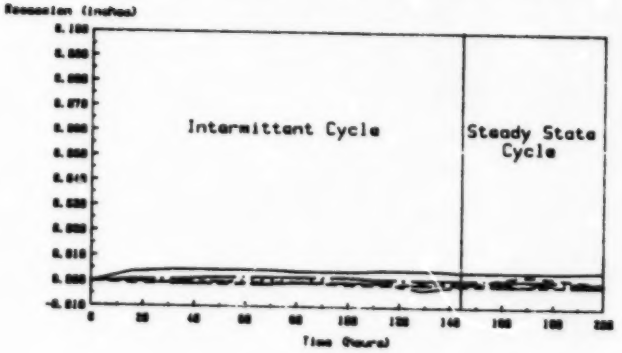


Figure 15

Exhaust Valve Seat Recession
IH 240, 0.10 gplg
cast iron valve seats

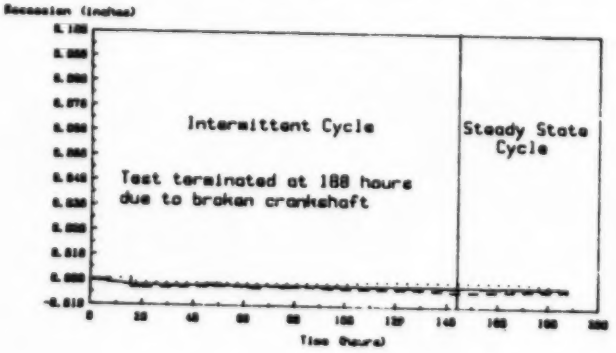
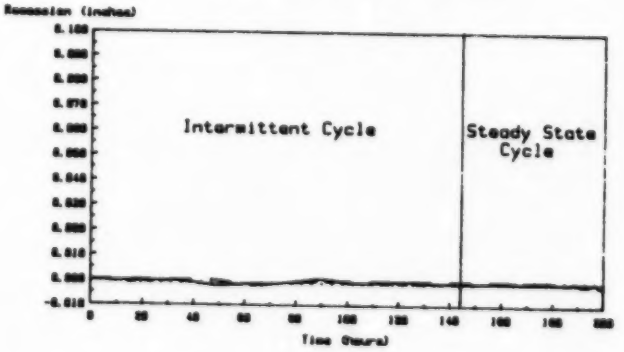


Figure 16

Exhaust Valve Seat Recession
IH 240, 0.10 gplg
cast iron valve seat inserts



APPENDIX C
GASOLINE AND DIESEL, TRACTOR AND COMBINE POPULATION ESTIMATES 1981-1993

APPENDIX C GASOLINE AND DIESEL TRACTOR AND COMBINE POPULATION ESTIMATES 1981-1993

Tractors

Information was taken from a number of sources to estimate the total 1990 gasoline and diesel tractor population. The 1981 Farm Energy Use Survey provided the information on the population of gasoline and diesel farm tractors according to engine size (14). Engine size catagories were: 0 to 40 hp, 40 to 99 hp, and 100 hp and over. The 1986 Census was used to update the 1981 tractor population and to calculate the growth rate for the whole fleet.

Sales figures were obtained from the Canadian Farm and Industrial Equipment Institute's (CFIEI) Industry Outlook which publishes yearly sales of farm equipment.

This basic information was used, along with some assumptions, to project population estimates of gasoline and diesel tractors. Since the horsepower categories for the sales data and Census do not match those used in the 1981 Farm Energy Use Survey, the population of tractors below 100 hp was redistributed in two classes of 20 to 49 hp and 50 to 99 hp. The total population of gasoline and diesel tractors was unchanged (14).

It was assumed that all tractors above 20 hp sold since 1981 were diesel-powered. Actual sales figures were taken from 1981 to 1986. Sales for the years 1987 to 1992 were assumed to be the same as 1986, a year with low sales.

Scrappage rates were estimated by subtracting yearly fleet growth from sales. The greatest uncertainty was in determining the proportion of scrapped gasoline-powered tractors.

Three scenarios were used. The first assumed that the number of gasoline tractors scrapped was proportional to their population. For example, if gasoline tractors represented 44.92% of all tractors between 20 and 49 hp in 1981 it was assumed that 44.92% of tractors scrapped were also gasoline-powered. The second assumed that twice as many gasoline tractors as diesels were being scrapped, and the third scenario supposed that only gasoline tractors were being scrapped. Since gasoline tractors are, on average, much older than diesels, the first scenario overestimates the number of gasoline tractors still in service in 1993 while the third underestimates that number.

The three scenarios were done for tractors from 20 to 49 hp, for tractors from 50 to 99 hp and for all tractors from 20 to 99 hp. Since the 1981 Farm Energy Use Survey

showed that only 1.4% of tractors above 100 hp were gasoline-powered, it was assumed that all tractors in this size class will be diesel-powered in 1993. The exclusion of tractors above 100 hp means that the proportion of diesel tractors in the fleet is higher than shown in the 20 to 99 hp scenario.

Combines

The same scenarios and methodology were run for combines as for tractors except that all combines were grouped together rather than being separated according to size. Also, the combine population is decreasing, largely due to the greater size and efficiency of newer models.

APPENDIX C

Tractors 20 - 49 hp*
All retirement tractors gas

Year	Gas Population	Diesel Population	Total Population	% Gas
1981	80 598	98 826	179 424	44.92
1982	76 816	104 152	180 968	42.45
1983	73 034	109 478	182 512	40.02
1984	69 252	114 804	184 056	37.63
1985	65 470	120 130	185 600	35.27
1986	61 688	125 456	187 144	32.96
1987	57 906	130 782	188 688	30.69
1988	54 124	136 108	190 232	28.45
1989	50 342	141 434	191 776	26.25
1990	46 560	146 760	193 320	24.08
1991	42 778	152 086	194 864	21.95
1992	38 996	157 412	196 408	19.85
1993	35 214	162 738	197 952	17.79

sales average 6 870
population increase average 1 544

Tractors 50 - 90 hp
Retirement proportional to population

Year	Gas Population	Diesel Population	Total Population	% Gas
1981	61 753	193 083	244 656	24.18
1982	59 949	196 889	256 838	23.34
1983	58 381	200 639	259 020	22.54
1984	56 867	204 335	261 202	21.77
1985	55 405	207 979	263 384	21.04
1986	53 992	211 574	265 566	20.33
1987	52 626	215 122	267 748	19.66
1988	51 306	218 624	269 930	19.01
1989	50 029	222 083	272 112	18.39
1990	48 794	225 500	274 294	17.79
1991	47 599	228 877	276 476	17.22
1992	46 443	232 215	278 658	16.67
1993	45 323	235 517	280 840	16.14

sales average 8 899
population increase average 2 182

* To convert horsepower to kilowatts, multiply the number of horsepower by 0.746.

Tractors 50 - 99 hp
Gas retirement twice diesel

Year	Gas Population	Diesel Population	Total Population	% Gas
1981	61 573	193 083	254 656	24.18
1982	58 957	197 881	256 838	22.96
1983	56 449	202 571	259 020	21.79
1984	54 045	207 257	261 202	20.69
1985	51 742	211 642	263 384	19.65
1986	49 536	216 030	265 566	18.65
1987	47 425	220 323	267 748	17.71
1988	45 403	224 527	269 930	16.82
1989	43 469	228 643	272 112	15.97
1990	41 618	232 676	274 294	15.17
1991	39 849	236 627	276 476	14.41
1992	38 156	240 502	278 658	13.69
1993	36 538	244 302	280 840	13.01

sales average 8 899
population increase average 2 182

Tractors 50 - 99 hp
All retirement tractors gas

Year	Gas Population	Diesel Population	Total Population	% Gas
1981	61 573	193 083	254 656	24.18
1982	54 856	201 982	256 838	21.36
1983	48 139	210 881	259 020	18.59
1984	41 422	219 780	261 202	15.86
1985	34 705	228 679	263 384	13.18
1986	27 988	237 578	265 566	10.54
1987	21 271	246 477	267 748	7.94
1988	14 554	255 376	269 930	5.39
1989	7 837	264 275	272 112	2.88
1990	1 120	273 174	274 294	0.41
1991	0	276 476	276 476	0.00
1992	0	278 658	278 658	0.00
1993	0	280 840	280 840	0.00

sales average 8 899
population increase average 2 182

Tractors 20 - 90 hp
Retirement proportional to population

Year	Gas Population	Diesel Population	Total Population	% Gas
1981	142 171	291 909	434 080	32.75
1982	138 227	299 579	437 806	31.57
1983	134 424	307 108	441 532	30.44
1984	130 758	314 500	445 258	29.37
1985	127 221	321 763	448 984	28.34
1986	123 809	328 901	452 710	27.35
1987	120 515	335 921	456 436	26.40
1988	117 335	342 827	460 162	25.50
1989	114 265	349 623	463 888	24.63
1990	111 298	356 316	467 614	23.80
1991	108 432	362 908	471 340	23.01
1992	105 661	369 405	475 066	22.24
1993	102 983	357 809	478 792	21.51

sales average 15 769
population increase average 3 726

Tractors 20 - 99 hp
Gas retirement twice diesel

Year	Gas Population	Diesel Population	Total Population	% Gas
1981	142 171	291 909	434 080	32.75
1982	136 229	301 577	437 806	31.12
1983	130 513	311 019	441 532	29.56
1984	125 017	320 241	445 258	28.08
1985	119 737	329 247	448 984	26.67
1986	114 666	338 044	452 710	25.33
1987	109 798	346 638	456 436	24.06
1988	105 128	355 034	460 162	22.85
1989	100 649	363 239	463 888	21.70
1990	96 354	371 260	467 614	20.61
1991	92 239	379 101	471 340	19.57
1992	88 297	386 769	475 066	18.59
1993	84 522	394 270	478 792	17.65

sales average 15 769
population increase average 3 726

Tractors 20 - 90 hp
All retirement tractors gas

Year	Gas Population	Diesel Population	Total Population	% Gas
1981	142 171	291 909	434 080	32.75
1982	133 854	303 952	437 806	30.57
1983	125 537	315 995	441 532	28.43
1984	117 220	328 038	445 258	26.33
1985	108 903	340 081	448 984	24.26
1986	100 586	352 124	452 710	22.22
1987	92 269	364 167	456 436	20.22
1988	83 952	376 210	460 162	18.24
1989	75 635	388 253	463 888	16.30
1990	67 318	400 296	467 614	14.40
1991	59 001	412 339	471 340	12.52
1992	50 684	424 382	475 066	10.67
1993	42 367	436 425	478 792	8.85

sales average 15 769
population increase average 3 726

Self-Propelled Combines
Retirement Proportional to Population

Year	Gas Population	Diesel Population	Total Population	% Gas	Sales
1981	79 946	34 584	114 530	69.80	4 915
1982	76 151	37 858	114 009	66.79	3 796
1983	73 268	40 220	113 488	64.56	2 920
1984	71 046	41 921	112 967	62.89	2 710
1985	69 014	43 432	112 446	61.38	2 322
1986	67 270	44 655	111 925	60.10	2 580
1987	65 406	45 998	111 404	58.71	2 580
1988	63 585	47 298	110 883	57.34	2 580
1989	61 807	48 555	110 362	56.00	2 580
1990	60 070	49 771	109 841	54.69	2 580
1991	58 374	50 946	109 320	53.40	2 580
1992	56 718	52 081	108 799	52.13	2 580
1993	55 102	53 176	108 278	50.89	

Average population decreaese 521

Self-Propelled Combines
Gas Retirement Twice that of Diesels

Year	Gas Population	Diesel Population	Total Population	% Gas	Sales
1981	79 946	34 584	114 530	69.80	4 915
1982	75 477	38 532	114 009	66.20	3 796
1983	72 038	41 450	113 488	63.48	2 920
1984	69 365	43 602	112 967	61.40	2 710
1985	66 907	45 539	112 446	59.50	2 322
1986	64 786	47 139	111 925	57.88	2 580
1987	62 512	48 892	111 404	56.11	2 580
1988	60 283	50 600	110 883	54.37	2 580
1989	58 099	52 263	110 362	52.64	2 580
1990	55 960	53 881	109 841	50.95	2 580
1991	53 866	55 454	109 320	49.27	2 580
1992	51 819	56 980	108 799	47.63	2 580
1993	49 818	58 460	108 278	46.01	

Average population decrease 521

Self-Propelled Combines
All Retirements Gasoline

Year	Gas Population	Diesel Population	Total Population	% Gas	Sales
1981	79 946	34 584	114 530	69.80	4 915
1982	73 989	40 020	114 009	64.90	3 796
1983	69 151	44 337	113 488	60.93	2 920
1984	65 189	47 778	112 967	57.71	2 710
1985	61 437	51 009	112 446	54.64	2 322
1986	58 073	53 852	111 925	51.89	2 580
1987	54 451	56 953	111 404	48.88	2 580
1988	50 829	60 054	110 883	45.84	2 580
1989	47 207	63 155	110 362	42.77	2 580
1990	43 585	66 256	109 841	39.68	2 580
1991	39 963	69 357	109 320	36.56	2 580
1992	36 341	72 458	108 799	33.40	2 580
1993	32 719	75 559	108 278	30.22	

Average population decrease 521

APPENDIX D
ASSOCIATIONS CONTACTED

APPENDIX D ASSOCIATIONS CONTACTED

1. Canadian Machine Builders Association.
2. Machinery and Equipment Manufacturer's Association of Canada.
3. Western Canadian Wheat Growers Association.
4. Canadian Farm and Industrial Equipment Institute.
5. Canadian Federation of Agriculture*.
6. Allied Boating Association of Canada.
7. Fisheries Council of Canada.
8. Fishing Vessel Owners Association of British Columbia.
9. Dominion Marine Association.
10. Atlantic Fishing Vessel Association*1.
11. Canadian Boating Federation.
12. Automotive Industries Association.
13. Canadian Automobile Association.
14. Canadian Automobile Sport Club Association.
15. Motor Vehicle Manufacturer's Association*2.
16. Canadian Driver's Club.
17. Dominion Automobile Association.
18. Truck Loggers Association.
19. Canadian Trucking Association*.
20. Motorcycle and Moped Industry Council.
21. Canadian Motorcycle Association Inc.*
22. The Antique and Classic Boat Society Inc.*3
23. Vintage Car Club of Canada.
24. Antique and Classic Car Club of Canada.
25. The Craven Foundation.
26. Canadian Outdoor Power Equipment Association*.

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* Response received by Environment Canada.

1 Response made by Sable Fish Packers Limited, Clark's Harbour, Nova Scotia.

2 Response made by General Motors.

3 Response made by Manotick Classic Boat Club.